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FEASIBILITY OF USING SCALE PATTERNS ANALYSIS TO IDENTIFY THE ORIGINS OF CHUM SALMON IN YUKON RIVER FISHERIES, 1987

by

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ABSTRACT

Analysis of scale patterns was investigated as a method of estimating stock composition of Yukon River fall chum salmon (Oncorhynchus keta Walbaum) harvests. Classification accuracies for eight-way stock of origin models of age 0.3 fish for the Toklat, Delta, Tanana (Bluff Cabin Slough), Chandalar, Sheenjek, Fishing Branch, mainstem Yukon, and Kluane Rivers were low for both males and females (25.1% and 26.3%, respectively) using scale character measurements alone. Classification accuracies of eight-way models incorporating mid-eye to fork-of-tail length measurements as a variable were also low (32.9% and 31.2% for males and females, respectively).

Three-way classifications to region of origin yielded mean classification accuracies of 56.5% and 54.2% for age-0.3 males and females, respectively, using scale characters alone, and 68.4% and 57.7%, respectively, when length was included as a variable. Classification results of a three-way region of origin model for age-0.3 males was used to estimate stock composition of weekly District 1 test fishing catches. Precision of estimates was considered unacceptably low.

KEY WORDS: Chum salmon, Oncorhynchus keta, stock separation, catch and run apportionment, linear discriminant analysis, Yukon River, Alaska.

INTRODUCTION

Yukon River chum salmon (Oncorhynchus keta Walbaum) are harvested in a wide range of fisheries in both marine and fresh waters. During their ocean residence, they are harvested in salmon gill net fisheries in the North Pacific Ocean and Bering Sea, in trawl fisheries in the Bering Sea, and in coastal purse seine and gill net fisheries of the Alaska Peninsula. They are the most abundant species returning to the Yukon River, averaging more than 1.5 million fish harvested annually (1982-86) by inriver commercial and subsistence fisheries in Alaska and Canada (Figures 1 and 2).

Chum salmon return to the Yukon River in two distinct seasonal runs termed summer and fall chum salmon. Summer chum salmon are the more abundant of the two with an average annual commercial and subsistence harvest of 1,097,000 fish (1982-86). They are characterized by their earlier run timing (early June to mid July), smaller size (average 6-7 lb), and rapid maturation in fresh water. Spawning occurs primarily in run-off tributaries in the lower 500 miles of the drainage and in the Tanana River system. Most summer chum salmon are harvested in a commercial gill net fishery in Districts 1 and 2 (1982-86 average 553,000 fish) and commercial and subsistence gill net and fish wheel fisheries in District 4 (1982-86 average 336,000 fish).

Fall chum salmon are distinguished by their later run timing (mid July to early September), larger size (average 7-8 lb), robust body shape, and bright silvery appearance. Fall stocks migrate further upstream and spawn primarily in spring-fed tributaries of the upper drainage which typically remain ice-free during the winter. Fall chum salmon are in great demand due to their appearance, size, and high oil content. They are harvested in commercial and subsistence fisheries in all Yukon River districts. An average of 62% (1982-86) of the annual total utilization (commercial and subsistence combined) occurred in the commercial gill net fishery in Districts 1 and 2 (1982-86 average 167,000 fish) and in a subsistence gill net and fish wheel fishery in District 5 (1982-86 average 96,000 fish).

High expoitation rates for fall chum salmon in the early 1980's have necessitated a conservative management approach in recent years. The total utilization of Yukon River fall chum salmon in the Alaska portion of the drainage increased 20% from the 1976-80 average of 399,000 fish to the 1981-85 average of 477,000 fish. Similarly, total utilization in Yukon Territory, Canada, increased from an average of 14,000 fish during 1976-80 to an average of 28,000 fish during 1981-85. This harvest increase was accompanied by a corresponding decline in escapements for most of the major spawning areas, especially in 1982-84. Escapements in the Sheenjek, Fishing Branch, Toklat, and Delta Rivers for the period 1982-84 averaged 42%, 60%, 59%, and 26%, respectively, below the escapement objectives established in 1987 for each of these streams (L. S. Buklis, Alaska Department of Fish and Game, Anchorage, personal communication).

Stock conservation concerns, especially for the 1986-88 returns, prompted fishery managers to adopt conservative management strategies with reduced fishing time and season closures. The Alaska Board of Fisheries reduced the lower Yukon River (Districts 1-3) commercial guideline harvest range for fall chum salmon from 110,000-220,000 to 0-110,000 fish beginning with the 1986 season. The guideline harvest range in the upper Yukon River (Districts 4-6) for fall chum and coho salmon combined was similarly reduced from 25,500-100,500 to 0-50,250 fish beginning in 1986. In 1987, the Alaska Department of Fish and Game (ADF&G) estimated fall chum salmon escapement to be insufficient to support commercial harvests. Consequently, no commercial harvest was legally permitted in the Alaskan portion of the drainage.

Management of chum salmon harvest in the lower Yukon River is complicated by an overlap in run timing of fall chum and summer chum salmon during July. There is evidence from mark and recapture studies conducted during the 1970's (Buklis and Barton 1984) that fall chum salmon destined for spawning tributaries farthest upstream begin entering the lower Yukon River during this transition period. Because stock composition information which details the relative abundance of each run is lacking, current Board of Fisheries management regulations require closure of the fishery in the lower river on July 15 for at least 2 to 3 weeks. This is done to protect the early portion of the fall run which is subject to high exploitation in upstream districts.

Accurate estimates of escapements and information about stock composition of Yukon River fall chum salmon harvests are essential to formulation and adoption of less conservative management strategies which will permit achievement of the Department's stated goal of optimum sustained yield.

ADF&G has investigated scale patterns analysis (SPA) as a possible method for obtaining estimates of Yukon River fall chum salmon stock contributions in 1974-77 and 1982 (summarized in Wilcock 1987). Investigators observed low classification accuracies of pooled age models and large differences in scale feature measurements between age groups. Inconclusive results from these studies lead to the general conclusion that the utility of scale patterns analysis could not be determined for Yukon River fall chum salmon unless 1) more accurate methods of aging could be developed, and 2) scale sampling programs were designed to meet SPA requirements for sample sizes and numbers of stocks sampled.

Genetic stock identification (GSI) is an alternative method of estimating stock composition using electrophoretic analysis of fish tissue proteins. This method was investigated by T.D.

Beacham (Department of Fisheries and Oceans, Nanaimo, B.C., personal communications) to estimate fall chum salmon stock contributions in Yukon River District 1 test fishing catches during 1985 and 1986. Baseline samples from individual stocks were collected from the Delta, Toklat, Sheenjek, Chandalar, mainstem Porcupine, Fishing Branch, Kluane, Koidern, Teslin, and mainstem Yukon Rivers during 1984-86. He estimated the average contribution of Alaskan stocks in 1985 and 1986 to be 39% and 62%, respectively, although discrimination between several of the major stocks was relatively poor.

Several drawbacks to using GSI techniques for Yukon River fall chum salmon include: 1) sample collection and processing are costly and logistically difficult, 2) preliminary results indicated possibly poor discrimination for some important stocks, particularly the Sheenjek and Kluane Rivers, and 3) interannual variability of allelic frequencies within stocks may be high, necessitating too frequent updating of known origin baseline samples (R. L. Wilmot, personal communications, USFWS, Anchorage).

ADF&G continued to investigate scale patterns analysis of fall chum salmon as a method of stock assessment in 1986 (Wilcock 1987) incorporating aging method and sample size improvements recommended by previous investigators. This work was continued since 1) the feasibility of GSI had not been completely established, 2) scales are collected annually for age-sex-size analyses, and 3) scale feature measurements may have utility when incorporated with electrophoresis results using maximum likelihood techniques. Classification accuracies obtained for five-way stock of origin models and three-way region of origin models were low for both age-0.3 and -0.4 fish. It was concluded that scale patterns analysis alone was not a feasible method of estimating stock composition in mixed stock harvests of Yukon River fall chum salmon. However, greatest observed differences between individual stocks were obtained for stocks exhibiting poor discrimination in previous GSI studies and consistent differences in fish length at age between stocks were noted. It was recommended that paired samples of tissues, scales, and standardized length measurements be collected in 1987 to assess the feasibility of using maximum likelihood techniques combining SPA, morphometric, and GSI results to improve discrimination between poorly differentiated stocks.

The U.S. Fish and Wildlife Service (USFWS) is currently investigating the utility of GSI techniques to estimate stock of origin in Yukon River fall chum salmon mixed stock harvests (R.L. Wilmot, USFWS, Anchorage, personal communications). Tissue samples from mixed stock fisheries and individual spawning escapements were collected jointly by ADF&G and USFWS during 1987 including a number of chum salmon spawning locations not previously sampled. The number of variable gene loci examined was also increased substantially to improve discrimination between stocks. Analysis of electrophoresis data by USFWS is currently underway and is scheduled for completion during the summer of 1988. All fish sampled for tissues were also sampled for scales and fish length. This report presents results for 1987 based on SPA and length measurements.

METHODS

One-way analysis of variance F-tests, a forward stepping F-to-enter/remove routine, frequency distributions, and classification accuracies of linear discriminant models were used to evaluate scale feature measurements and fish length measurements for inclusion in maximum likelihood analysis of combined SPA, morphometric, and GSI data. In addition, classification accuracies of linear discriminant models were used to assess the feasibility of using scale feature measurements and fish length measurements to estimate stock contributions of fall chum salmon to Yukon River harvests and to estimate the proportions of summer and fall chum salmon present during the mid-July transition between seasonal races.

Yukon River summer and fall chum salmon escapements and District 1 commercial and test fishing catches were sampled for age, sex, and size information using standard scale sampling techniques. Sample goals were established according to statewide standards to meet predetermined levels of accuracy and precision for estimating age composition (D. R. Bernard, R. H. Conrad, L. K. Brannian, ADF&G, Anchorage, personal communications). Scales were collected from the left side of the fish approximately two rows above the lateral line and on the diagonal row downward from the posterior insertion of the dorsal fin (INPFC 1963). Scales were mounted on gum cards and impressions were made in cellulose acetate (Clutter and Whitesel 1956). Vertebrae were collected for age determination (Clark 1987) from all spawning fall chum salmon sampled in Alaska, from all fish sampled for tissues at the Fishing Branch weir, and from a portion of fish sampled for tissues from the Canadian mainstem Yukon and Kluane Rivers. Ages were recorded in European notation. Sex was determined by examination of external morphology or by examination of gonads. Length measured on all fish sampled in Alaska was from mid-eye to fork-of-tail (MEF). Fish sampled in Canada were measured from tip-of-snout to fork-of-tail (TSFT).

Selection of Standards

Major spawning stocks included in model construction were represented by scales sampled from escapements to the Delta, Toklat, Tanana (Bluff Cabin Slough), Chandalar, Sheenjek, Fishing Branch, Kluane, and mainstem Yukon Rivers. Sample goals for the Toklat, Delta, and Sheenjek River escapements were 450 samples for age, sex, and length from each stream to obtain an age composition estimate for a population with three major age groups at a 90% chance of being within ±0.05 percentage points of the true proportion. Of these 450 samples, 150 live fish from each river were sacrificed for paired samples of tissues, scales, and length data. This sample size of 150 fish was recommended by the USFWS to conservatively obtain acceptable levels of accuracy and precision using GSI techniques. Samples from the Delta and Toklat Rivers were collected during peak spawner die-off, with age, sex, and length information collected primarily from carcasses. Samples from the Sheenjek River were collected during the later portion of the spawning migration from beach seine catches made during operation of a sidescan sonar escapement enumeration project.

Sample goals for Bluff Cabin Slough on the Tanana River and for the Chandalar, Fishing Branch, Kluane and mainstem Yukon Rivers were 150 fish from each stream sampled for tissues, age, sex, and length based on USFWS goals for GSI samples.

Age, sex, and length sample goals for chum salmon sampled in Canada were established by Canadian Department of Fisheries and Oceans (DFO) personnel. Samples of fish from the Fishing Branch River were collected from up to 40 live fish per day passing through a weir. Paired samples of 75 fish each representing spawning escapements to the mainstem Yukon River in Canada were collected from two locations, one near Minto Landing and one near the mouth of Tatchun Creek. Radiotelemetry studies (Milligan et. al 1984) have indicated that escapements to the mainstem Yukon River and White River sub-basin (including the Kluane and Koidern Rivers) comprise 60% and 34%, respectively, of fall chum escapements in Yukon Territory.

Because previous studies had indicated scale patterns analysis alone of Yukon River fall chum salmon was unlikely to provide a feasible method of estimating stock composition, the analysis was limited to samples for which paired tissue, scale, and length information had been collected. Scale feature measurements were made for all paired samples which had usable scales. Comparisons of scale feature and length measurements between age groups and sexes indicated substantial differences between groups. To avoid potential confounding of results through interactions, subsequent analyses were stratified by sex and limited to the most abundant age class (age-0.3). This age group represented 70-96% of all sampled escapements in 1987 (Wilcock In press), except the Chandalar River (55%) .

Eight-way classification models using scale features alone and using scale features combined with fish lengths were constructed for each sex using samples from individual fall chum salmon spawning escapements. In addition, three-way (Tanana, Porcupine, and Canadian Yukon) models were constructed to test the utility of pooled stock standards for region of origin models. Samples from Bluff Cabin Slough and the Delta and Toklat Rivers were used to represent the Tanana River drainage standard, while samples from the Chandalar, Sheenjek, and Fishing Branch Rivers represented the Porcupine region standard. Samples representing the Canadian Yukon regional standard were selected from the Kluane and mainstem Yukon River samples. Samples from individual stocks were selected in proportion to their estimated escapement abundance (Table 1) as indicated by 1) expanded multiple surveys for the Toklat and Delta Rivers; 2) foot survey for Bluff Cabin Slough, 3) sonar counts for the Chandalar and Sheenjek Rivers; 4) a weir count for the Fishing Branch River; and 4) aerial survey proportions applied to preliminary population estimates from tagging studies for the Kluane and mainstem Yukon Rivers.

Two-way classification models for summer chum and fall chum salmon were constructed for both age-0.3 male and female fish. Scale samples representing the fall chum salmon run were selected from the Delta, Toklat, Tanana (Bluff Cabin Slough), Chandalar, Sheenjek, Fishing Branch, Kluane, and mainstem Yukon Rivers. Scales representing the summer chum salmon run were selected from samples of the Anvik, Andreafsky, Nulato, and Jim River escapements. All samples were selected in proportion to their estimated escapement abundance pooled for each seasonal race. Anvik River samples comprised approximately 83% of the summer chum salmon stock standards.

Scale Features Measurement

Measurements of scale features were made using standardized fish scale digitizing techniques. Scale images were projected at 100X magnification using equipment similar to that described by Ryan and Christie (1976), and measurements were made and recorded by a microcomputer-controlled digitizing system. Measurements were taken along a standard drawing axis about 20° dorsal of the primary axis (a posterior-anterior line approximately perpendicular to the sculptured field). The distance between each circulus along the axis in selected scale growth zones was recorded.

Two growth zones were measured for all fall chum salmon scales (Figure 3) examined as follows: (1) scale focus to the last circulus of the first annular growth zone, and (2) the last circulus of the first annular growth zone to the last circulus of the second annular growth zone. In addition, total distance from the last circulus of the second annular growth zone to the last circulus of the third annular growth zone was measured for age-0.3 and older fish. The total distance from the last circulus of the third annulus to the last circulus of the fourth annulus (the fourth annular zone) was also measured for age-0.4 and age-0.5 fish. Incremental distances and circuli counts were used to calculate 86 scale characters (Appendix A). Due to resorption of some scales, most analyses of age-0.3 chum salmon were confined to scale characters calculated for the first and second annular zones.

Length Measurement Standardization

Linear regressions of MEF and TSFT length data for fall chum salmon sampled from the Kluane and mainstem Yukon Rivers in 1985 (Appendix B) were used to estimate MEF lengths for Fishing Branch, Kluane, and Mainstem Yukon River fall chum salmon samples in 1987.

Selection of Variables

Mean, variance, and one-way analysis of variance F-statistic were calculated for each scale character and MEF length to evaluate their discriminatory utility. Selection of scale characters for the analysis was by a forward stepping procedure using partial F-statistics as the criteria for entry/deletion of variables (Enslein et al. 1977). Selected variables were entered into or removed from a linear discriminant function (Fisher 1936) in a step-wise manner. At each step, a classification matrix of actual vs. classified groups of origin, and a mean classification accuracy were calculated using the leaving-one-out procedure of Lachenbruch (1967). Frequency distributions were plotted for each selected scale variable and subjectively examined for violations of assumed normality. Statistical tests for normality were not applied as the method has been shown to be robust to violations of normality. Subjective examination was primarily to detect bimodality, extreme skewness or kurtosis, and data outliers due to recording and measurement errors.

Evaluation of Discriminant Models

Discriminant models which produced the highest classification accuracies and included only variables with acceptable frequency distributions were selected and evaluated. In general, researchers using SPA techniques seek classification accuracies at least 20-30% greater than random chance. If classification accuracies are acceptable, stock composition estimates with 90% confidence intervals which are within ±25-30% of the estimate are sought.

RESULTS AND DISCUSSION

Mean classification accuracies of eight-way models for individual spawning stocks using scale features alone (Table 2) were low for both male and female age-0.3 fish (25.1% and 26.3%, respectively). Models employing MEF length as well as scale measurements (Table 3) yielded improved mean accuracies for both sexes (32.9% for males and 31.2% for females), but were still considered unacceptably low. Misclassifications of individual stocks were generally greatest among stocks within regional groupings. Fish from the Chandalar River displayed the highest classification accuracies in stock of origin models for males. Kluane River fish were most frequently correctly classified for female stock of origin models.

Three-way models with individual spawning stocks pooled into geographic regions of origin (Table 4) also yielded low classification accuracies using scale features alone (56.5% and 54.2% for males and females, respectively). Including MEF length as a variable (Table 5) improved performance of region of origin models for both sexes (68.4% and 57.7% for males and females, respectively) as it did in the stock of origin models. Canadian Yukon stocks generally were most frequently classified correctly (range from 64.0% to 67.4%). Tanana drainage stocks displayed poorest classification accuracies for all three-way models, ranging from 42.1% to 61.9%.

Mean classification accuracy of the region of origin model for age-0.3 males (68.4%) was considered marginally acceptable and classification results were used to estimate stock composition of weekly catches of fall chum salmon in District 1 test fisheries (Table 6). Confidence intervals for these estimates were large and precision of the estimates was judged to be unacceptably low due to poor model accuracy and small sample sizes.

Major scale measurement variables selected for construction of models varied considerably between males and females. Variables selected for female fall chum salmon were consistent for all models. The incremental distance of the first three circuli in the first annular zone, the number of circuli in the first half of the first annular zone, and the incremental distance of the first three circuli in the second annular zone were chosen as the first, second, and third variables for all models.

Variables included in models representing male age-0.3 fall chum salmon differed considerably between models using length and models without length measurements, as well as between stock of origin and region of origin models. Scale variables most frequently selected for males were the same three variables which were selected for females as listed above.

Inclusion of MEF length measurements as a variable improved the accuracy of each model examined for both males and females and for both stock and region of origin grouping schemes. Length was selected as the primary variable in each model. However, problems exist with using length measurements which may need to be more closely examined. An assumption of using length measurements of fish from escapements to estimate stock composition of harvests is that the size distribution for each stock is the same in mixed stock harvests as it is in individual escapements. For example, because of the selective nature of gill nets, there may be potentially significant exploitation differences by stock, and biases in stock composition estimates, if selection is greater for larger fish or males. Selection in the fishery for specific age, sex, or sizes could directly influence the observed age, sex, and size distributions in escapements.

In addition, differing methods of length measurements between collecting agencies may affect the performance of models using length as a variable. Considering the highly correlated relationship between MEF and TSFT lengths observed for 1985 data (r^2 values of 0.922 and 0.930 for males and females, respectively), this problem is probably minimal. A greater potential source of error is that associated with estimating fork length for spawning fish, particularly females, which experience considerable damage to caudal fin rays during redd construction and mating activities. Variability in length measurements between individual samplers may be great when trying to estimate the length of missing caudal fin rays. This problem is probably greatest for samples from carcasses and post-spawners than from migrating fish and pre-spawners.

Comparisons of group means, standard errors, and one-way analysis of variance F-test for annular growth zones and MEF lengths of age-0.3 male and female fish are presented in Appendix C.

Previous stock identification studies of Yukon River fall chum salmon (Wilcock 1987) which used models for three to five individual tributary stocks resulted in mean classification accuracies ranging from 1.3 to 2.3 times what would be expected from random chance alone. Eight-way stock of origin classifications in 1987 yielded similar results (2.0 and 2.1 times random chance for males and females, respectively) using scale measurements only. Mean classification accuracies for three-way models of Tanana, Porcupine, and Canadian Yukon stock groupings in 1987 were generally higher (56.5% and 54.2% for age-0.3 males and females, respectively) than previous years (range of 44.1% to 54.6%). Three-way models for previous years were generally constructed from pooled sexes and ages.

Two-way models classifying 1987 summer chum and fall chum salmon to run of origin yielded classification accuracies for age-0.3 male and female samples of 71.2% and 80.8%, respectively (Table 7). Because fish size is generally noted as one of the distinguishing characteristics between the two seasonal runs, length was included as a variable in all comparisons between summer and fall chum salmon in 1987. Classification results were generally higher than those observed in previous years (range from 59.1% to 67.1%) for which models were constructed for samples from sexes pooled and confined to scale measurements only.

CONCLUSIONS

Classification accuracies of SPA studies from 1974-77 and 1982 were generally low, and recommendations were made for continuation of feasibility studies only with improvements to sampling design and aging techniques. Fall chum salmon SPA studies in 1986 incorporated recommended changes for larger sample sizes, greater numbers of spawning stocks sampled, and the use of vertebrae for aging. However, mean classification accuracies obtained in 1986 were also considered to be too low to justify the digitizing of mixed stock composition catch samples.

Juvenile chum salmon migrate seaward soon after emergence and are not subject to the extensive differential environmental influences that are typical for freshwater rearing species such as chinook and sockeye salmon. There do not appear to be substantial growth history differences which are identifiable using scale patterns analysis techniques between component stocks of Yukon River fall chum salmon. T. D. Beacham (personal communication, DFO, Nanaimo, B.C.) has recently shown electrophoretic analysis of tissue proteins to have some utility in identifying fall chum salmon component stocks based on genetic differences between spawning populations. However, he observed poor discrimination for several major contributing stocks, particularly between fish from the Sheenjek River and fish from the Kluane and Koidern Rivers.

Although stock discrimination from most SPA studies was generally poor, Sheenjek River samples (which showed poor separability using electrophoresis) produced the highest classification accuracies observed in scale patterns models from 1976 and 1986. In addition, mean body length measurements of fall chum salmon sampled from the Sheenjek River have consistently been larger than measurements for fish sampled from other Yukon River escapements (McBride et al. 1983; Buklis and Wilcock 1984, 1985, 1986; Buklis 1987; Wilcock In press). It is very possible that results from electrophoresis, scale patterns analysis, and morphometric measurements combined in maximum likelihood estimation can provide stock composition estimates more accurate and precise than are obtainable with any single stock identification method.

The USFWS has continued to investigate GSI techniques and is currently finalizing the analysis of electrophoresis data collected in 1987. Although scale patterns analysis alone has not proven to be a feasible method of estimating stock composition in mixed stock harvests of Yukon River fall chum salmon, scales and length measurements were collected for all fish sampled for tissues in 1987 to assess the feasibility of combining SPA, morphometric, and electrophoretic results.

Classification accuracies obtained for linear discriminant models of scale character measurements for fish sampled for scales and tissues in 1987 were once again unacceptably low. The addition of length measurements as a variable in the analysis improved classification accuracies considerably for all models examined. However, results for only one model, a region of origin grouping for age-0.3 males, were considered sufficiently accurate to justify estimation of stock composition of District 1 test fishing catches. Precision of resulting estimates was considered unacceptably low. It was again concluded that the use of current scale patterns analysis techniques does not provide a feasible method of estimating stock composition of mixed stock harvests of Yukon River fall chum salmon.

The considerable increase in classification accuracies provided by inclusion of mid-eye to fork-of-tail length measurements in the linear discriminant analysis did not immediately provide a feasible stock identification tool. This gain in accuracy did indicate good potential for utility of these data in maximum likelihood methods combining data types. However, it is recommended that biases introduced by selectivity of gear and measurement of lengths involving fork-of-the-tail be further evaluated.

Scale variables with potential utility for increasing discrimination between stocks in GSI investigations were selected on an initial basis during the process of evaluating SPA techniques in 1987. It is recommended that scale variables and MEF length measurements be further evaluated for fall chum salmon stock identification utility when results from USFWS genetic studies become available.

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Table 1. Age and sex composition of Yukon River fall chum salmon escapement to major spawning areas, 1987.

Location and Estimation Method	Escapement Estimate	Sample Size	Sex		Brood Year and Age Group 1984	1983	1982	1981	
					0.2	0.3	0.4	0.5	Total
Toklat River a Expanded Multiple Surveys	22,141	430	Female	Percent of Sample	1.4	35.3	6.7	0.5	44.0
				Number in Escapement	309	7,827	1,493	103	9,732
			Male	Percent of Sample	3.3	43.7	9.1	0.0	56.0
				Number in Escapement	721	9,680	2,008	0	12,409
			Combined	Percent of Sample	4.7	79.1	15.8	0.5	100.0
				Number in Escapement	1,030	17,507	3,501	103	22,141
				Standard Error	225	435	390	73	
Delta River a Expanded Multiple Surveys	21,180	429	Female	Percent of Sample	0.9	33.6	12.6	0.2	47.3
				Number in Escapement	198	7,109	2,666	49	10,022
			Male	Percent of Sample	0.9	37.1	14.0	0.7	52.7
				Number in Escapement	198	7,850	2,962	148	11,158
			Combined	Percent of Sample	1.9	70.6	26.6	0.9	100.0
				Number in Escapement	396	14,959	5,628	197	21,180
				Standard Error	138	466	452	98	
Bluff Cabin Slough b Foot Survey	9,395	145	Female	Percent of Sample	0.7	39.3	0.0	0.0	40.0
			Male	Percent of Sample	0.7	56.6	2.8	0.0	60.0
			Combined	Percent of Sample	1.4	95.9	2.8	0.0	100.0
				Standard Error	1.0	1.7	1.4	0.0	
Chandalar River c Sonar Count	52,416	134	Female	Percent of Sample	0.0	11.9	11.2	0.7	23.9
				Number in Escapement	0	6,259	5,867	391	12,517
			Male	Percent of Sample	0.0	43.3	30.6	2.2	76.1
				Number in Escapement	0	22,688	16,038	1,173	39,899
			Combined	Percent of Sample	0.0	55.2	41.8	3.0	100.0
				Number in Escapement	0	28,946	21,905	1,565	52,416
				Standard Error	0.0	2,260	2,242	773	
Sheenjek River d Sonar Count	140,086	430	Female	Percent of Sample	1.4	59.1	5.1	0.7	66.3
				Number in Escapement	1,955	82,748	7,167	977	92,847
			Male	Percent of Sample	0.7	30.7	2.1	0.2	33.7
				Number in Escapement	977	43,003	2,932	326	47,238
			Combined	Percent of Sample	2.1	89.8	7.2	0.9	100.0
				Number in Escapement	2,932	125,752	10,099	1,303	140,086
				Standard Error	968	2,050	1,749	649	
Fishing Branch River e Weir Count	48,956	157	Female	Percent of Sample	0.0	35.0	7.0	0.0	42.0
				Number in Escapement	0	17,150	3,430	0	20,580
			Male	Percent of Sample	0.0	49.7	8.3	0.0	58.0
				Number in Escapement	0	24,322	4,054	0	28,376
			Combined	Percent of Sample	0.0	84.7	15.3	0.0	100.0
				Number in Escapement	0	41,472	7,484	0	48,956
				Standard Error	0.0	1,411	1,411	0.0	
Mainstem Yukon River f Minto and Tatchun Cr. Areas Peak Aerial Survey Index of Abundance	6,115	143	Female	Percent of Sample	0.0	60.8	3.5	0.0	64.3
			Male	Percent of Sample	0.0	30.8	4.9	0.0	35.7
			Combined	Percent of Sample	0.0	91.6	8.4	0.0	100.0
				Standard Error	0.0	2.3	2.3	0.0	
Kluane River f Peak Aerial Survey Index of Abundance	12,000	143	Female	Percent of Sample	0.0	41.3	6.3	0.0	47.6
			Male	Percent of Sample	0.0	42.0	10.5	0.0	52.4
			Combined	Percent of Sample	0.0	83.2	16.8	0.0	100.0
				Standard Error	0.0	3.1	3.1	0.0	

a All samples were from carcasses except 150 samples taken from beach seine catches.
b All sampled fish captured using spears and dip-nets.
c All samples from 5-5/8 in (14.3 cm) mesh set gill net catches.
d All samples collected from beach seine catches.
e All samples collected from live fish passing through a weir.
f All samples collected from unspecified mesh size gill net catches.

Table 2. Classification accuracies of linear discriminant models using scale feature measurements to classify age-0.3 Yukon River fall chum salmon to stock of origin, 1987.

Males

Actual River of Origin	Sample Size	Classified River of Origin: Toklat	Delta	Bluff Cabin	Chandalar	Sheenjek	Fishing Branch	Mainstem Yukon	Kluane
Toklat	52	0.115	0.269	0.096	0.212	0.058	0.154	0.077	0.019
Delta	46	0.109	0.283	0.174	0.065	0.065	0.109	0.152	0.043
Bluff Cabin	69	0.029	0.290	0.203	0.116	0.087	0.087	0.101	0.087
Chandalar	44	0.091	0.023	0.045	0.591	0.136	0.114	0.000	0.000
Sheenjek	30	0.100	0.033	0.100	0.333	0.100	0.100	0.100	0.133
Fishing Branch	75	0.080	0.080	0.107	0.120	0.067	0.267	0.067	0.213
Mainstem Yukon	38	0.053	0.184	0.053	0.053	0.000	0.184	0.237	0.237
Kluane	57	0.035	0.158	0.105	0.000	0.035	0.123	0.333	0.211

Mean Classification Accuracy = 0.251

Variables in the Analysis: 20, 44, 33, 72.
(Refer to Appendix A)

Females

Actual River of Origin	Sample Size	Classified River of Origin: Toklat	Delta	Bluff Cabin	Chandalar	Sheenjek	Fishing Branch	Mainstem Yukon	Kluane
Toklat	61	0.098	0.098	0.082	0.213	0.098	0.115	0.049	0.246
Delta	57	0.070	0.123	0.211	0.193	0.035	0.193	0.000	0.175
Bluff Cabin	49	0.143	0.061	0.327	0.143	0.102	0.082	0.000	0.143
Chandalar	15	0.133	0.067	0.133	0.533	0.133	0.000	0.000	0.000
Sheenjek	80	0.125	0.025	0.112	0.262	0.125	0.162	0.038	0.150
Fishing Branch	52	0.038	0.115	0.192	0.115	0.038	0.269	0.038	0.192
Mainstem Yukon	77	0.104	0.104	0.065	0.078	0.065	0.104	0.065	0.416
Kluane	57	0.000	0.053	0.105	0.053	0.018	0.088	0.123	0.561

Mean Classification Accuracy = 0.263

Variables in the Analysis: 4, 33, 43, 24.
(Refer to Appendix A)

Table 3. Classification accuracies of linear discriminant models using scale feature measurements and MEF length to classify male and female age-0.3 Yukon River fall chum salmon to stock of origin, 1987.

Males

Actual River of Origin	Sample Size	Toklat	Delta	Bluff Cabin	Chandalar	Sheenjek	Fishing Branch	Mainstem Yukon	Kluane
		Classified River of Origin							
Toklat	52	0.365	0.173	0.077	0.000	0.115	0.135	0.077	0.058
Delta	46	0.217	0.457	0.043	0.065	0.022	0.065	0.087	0.043
Bluff Cabin	69	0.203	0.304	0.072	0.043	0.072	0.058	0.188	0.058
Chandalar	44	0.045	0.023	0.000	0.591	0.136	0.205	0.000	0.000
Sheenjek	30	0.033	0.100	0.000	0.300	0.367	0.067	0.033	0.100
Fishing Branch	75	0.133	0.080	0.027	0.107	0.133	0.307	0.053	0.160
Mainstem Yukon	38	0.184	0.158	0.053	0.000	0.000	0.132	0.211	0.263
Kluane	57	0.140	0.105	0.000	0.000	0.035	0.140	0.316	0.263

Mean Classification Accuracy = 0.329

Variables in the Analysis: Length, 21, 4, 45, 83.
(Refer to Appendix A)

Females

Actual River of Origin	Sample Size	Toklat	Delta	Bluff Cabin	Chandalar	Sheenjek	Fishing Branch	Mainstem Yukon	Kluane
		Classified River of Origin							
Toklat	61	0.361	0.033	0.115	0.066	0.000	0.082	0.131	0.213
Delta	57	0.105	0.123	0.193	0.193	0.053	0.211	0.088	0.035
Bluff Cabin	49	0.184	0.163	0.367	0.061	0.020	0.020	0.082	0.102
Chandalar	15	0.000	0.133	0.067	0.533	0.067	0.133	0.067	0.000
Sheenjek	80	0.050	0.075	0.038	0.387	0.150	0.162	0.075	0.063
Fishing Branch	52	0.019	0.135	0.192	0.077	0.115	0.250	0.154	0.058
Mainstem Yukon	77	0.156	0.065	0.104	0.091	0.104	0.078	0.130	0.273
Kluane	57	0.070	0.018	0.123	0.035	0.000	0.053	0.123	0.579

Mean Classification Accuracy = 0.312

Variables in the Analysis: Length, 4, 33, 43.
(Refer to Appendix A)

Table 4. Classification accuracies of linear discriminant models using scale feature measurements to classify male and female age-0.3 Yukon River fall chum salmon to region of origin, 1987.

Males

Actual Region of Origin	Sample Size	Classified Region of Origin: Tanana	Porcupine	Canadian Yukon
Tanana	113	0.434	0.265	0.301
Porcupine	51	0.255	0.588	0.157
Canadian Yukon	86	0.186	0.140	0.674
		Mean Classification Accuracy =		0.565

Variables in the Analysis: 4, 41, 82, 62.
(Refer to Appendix A)

Females

Actual Region of Origin	Sample Size	Classified Region of Origin: Tanana	Porcupine	Canadian Yukon
Tanana	140	0.421	0.307	0.271
Porcupine	69	0.261	0.565	0.174
Canadian Yukon	86	0.198	0.163	0.640
		Mean Classification Accuracy =		0.542

Variables in the Analysis: 4, 33, 43, 3.
(Refer to Appendix A)

Table 5. Classification accuracies of linear discriminant models using scale feature measurements and MEF length to classify male and female age-0.3 Yukon River fall chum salmon to region of origin, 1987.

Males

Actual Region of Origin	Sample Size	Classified Region of Origin: Tanana	Porcupine	Canadian Yukon
Tanana	113	<u>0.619</u>	0.204	0.177
Porcupine	51	0.157	<u>0.745</u>	0.098
Canadian Yukon	86	0.221	0.093	<u>0.686</u>
		Mean Classification Accuracy =		0.684

Variables in the Analysis: Length, 4, 72, 33, 44, 84.
(Refer to Appendix A)

Females

Actual Region of Origin	Sample Size	Classified Region of Origin: Tanana	Porcupine	Canadian Yukon
Tanana	140	<u>0.457</u>	0.279	0.264
Porcupine	69	0.246	<u>0.623</u>	0.130
Canadian Yukon	86	0.221	0.128	<u>0.651</u>
		Mean Classification Accuracy =		0.577

Variables in the Analysis: Length, 4, 33, 43.
(Refer to Appendix A)

Table 6. Estimated region of origin stock composition for weekly Yukon River District 1 test fishing catches of male age-0.3 fall chum salmon using linear discriminant functions of scale variables and MEF length, 1987.

Dates	Sample Size	Region of Origin	Prop. of Catch	90 Percent Confidence Interval Lower Bound	90 Percent Confidence Interval Upper Bound
7/16-7/22	24	Tanana	0.964	0.429	1.499
		Porcupine	0.332	-0.113	0.778
		Canadian Yukon	-0.296	-0.476	-0.116
7/23-7/29	49	Tanana	0.573	0.192	0.955
		Porcupine	0.323	0.033	0.613
		Canadian Yukon	0.103	-0.156	0.363
8/6-8/12	61	Tanana	0.365	0.027	0.702
		Porcupine	0.600	0.311	0.888
		Canadian Yukon	0.035	-0.180	0.251
8/13-8/19	59	Tanana	0.530	0.179	0.880
		Porcupine	0.391	0.115	0.667
		Canadian Yukon	0.079	-0.153	0.312
8/20-8/27	51	Tanana	0.495	0.126	0.864
		Porcupine	0.405	0.113	0.696
		Canadian Yukon	0.100	-0.149	0.350

Table 7. Classification accuracies of linear discriminant models using scale feature measurements and MEF length to classify male and female age-0.3 Yukon River chum salmon to seasonal run of origin, 1987.

Males

Actual Run of Origin	Sample Size	Classified Run of Origin: Summer Chum Salmon	Classified Run of Origin: Fall Chum Salmon
Summer Chum Salmon	47	0.723	0.277
Fall Chum Salmon	80	0.300	0.700
		Mean Classification Accuracy =	0.712

Variables in the Analysis: Length, 1.
(Refer to Appendix A)

Females

Actual Run of Origin	Sample Size	Classified Run of Origin: Summer Chum Salmon	Classified Run of Origin: Fall Chum Salmon
Summer Chum Salmon	40	0.850	0.150
Fall Chum Salmon	107	0.234	0.766
		Mean Classification Accuracy =	0.808

Variables in the Analysis: 4, 33, 43, 3.
(Refer to Appendix A)

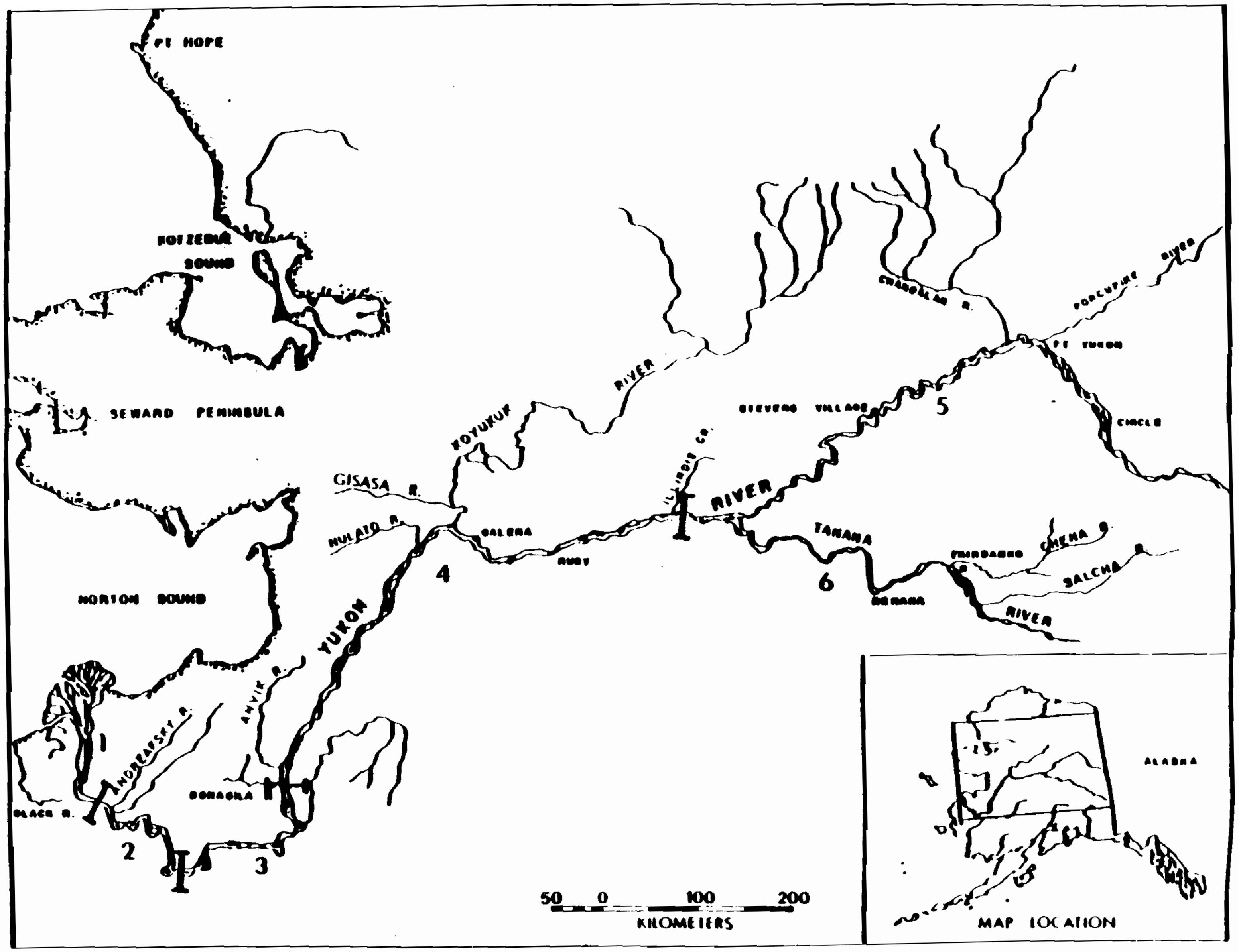

Figure 1. Alaskan portion of the Yukon River showing the six regulatory districts.

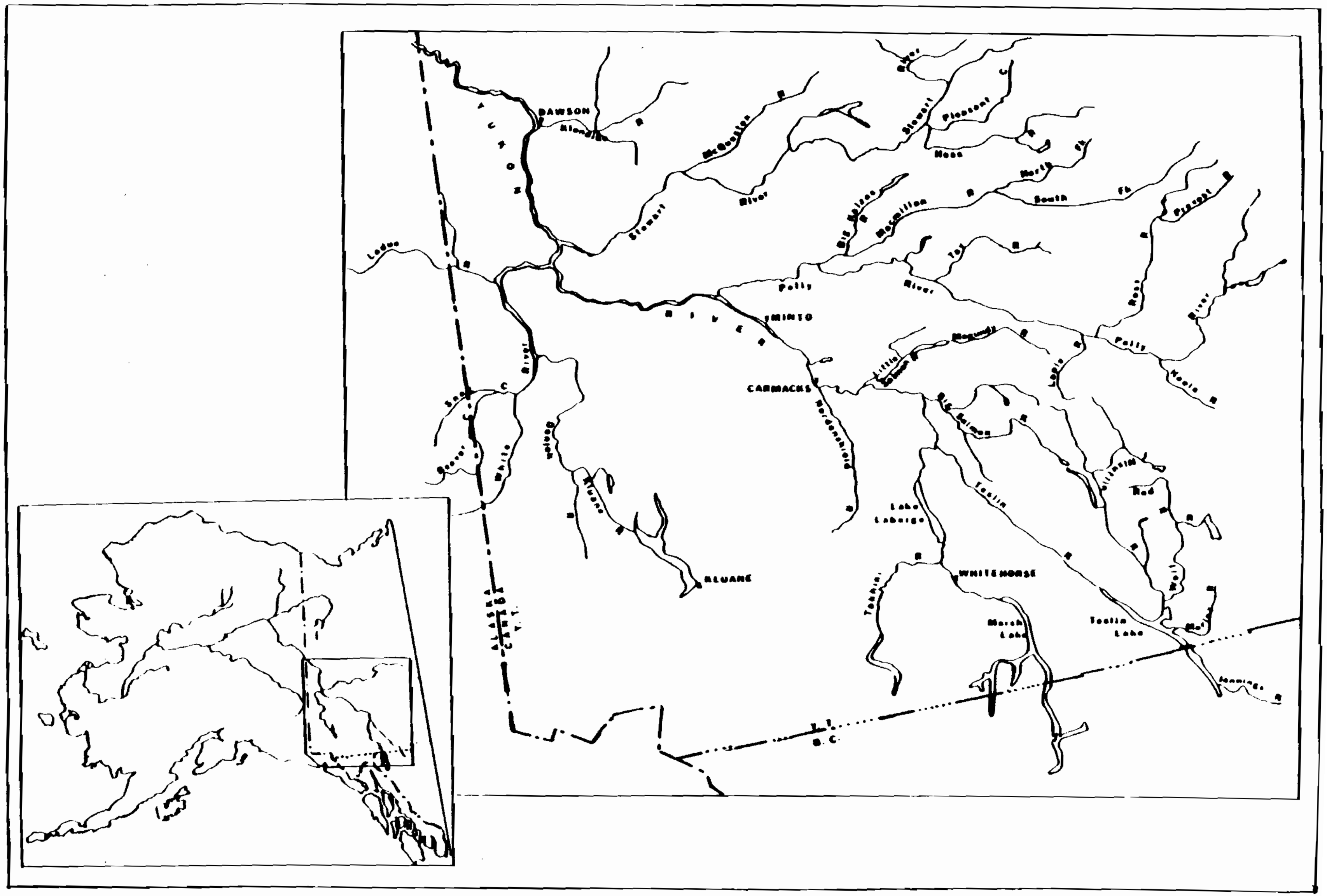

Figure 2. Canadian portion of the Yukon River.

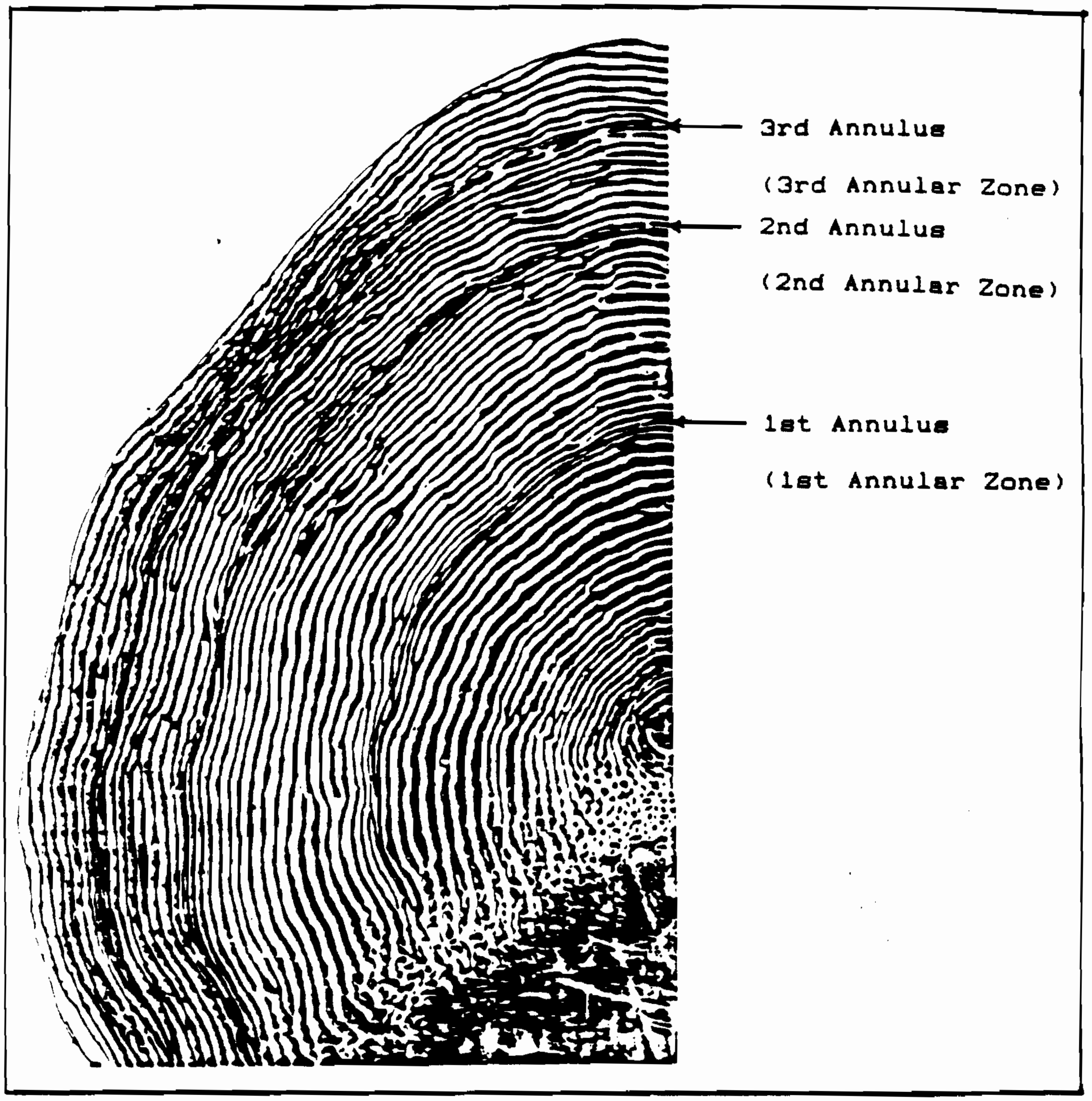

Figure 3. Age-0.3 chum salmon scale showing growth zones measured for linear discriminant analysis of Yukon River chum salmon, 1987.

APPENDIX A: SCALE VARIABLES SCREENED

Appendix A. Scale variables screened for linear discriminant function analysis of Yukon River chum salmon, 1987.

Variable	1st Annular Zone
1	Number of circuli (NC1AZ)[a]
2	Width of zone (S1AZ)[b]
3	Distance, focus (CO) to circulus 3 (C3)
4 (20)	Distance, CO-C6
5	Distance, CO-C9
6 (22)	Distance, CO-C12
7	Distance, CO-C15
8 (24)	Distance, C3-C9
9	Distance, C3-C12
10 (26)	Distance, C3-C15
11	Distance, C6-C12
12 (28)	Distance, C6-C15
13	Distance, C9-C15
14 (30)	Distance, C(NC1AZ -6) to end of zone
15	Distance, C(NC1AZ -3) to end of zone
16	Distance, C3 to end of zone
17	Distance, C9 to end of zone
18	Distance, C15 to end of zone
19-31	Relative widths, (variables 3-15)/S1AZ
32	Average interval between circuli, S1AZ/NC1AZ
33	Number of circuli in first 1/2 of zone
34	Minimum distance between 2 consecutive circuli
35	Maximum distance between 2 consecutive circuli
36	Relative width, (variable 34)/S1AZ
37	Relative width, (variable 35)/S1AZ
38	Number incremental distances less than 10
39	Number incremental distances between 10 and 20
40	Number incremental distances greater than 20

Variable	2nd Annular Zone
41	Number of circuli (NC2AZ)[c]
42	Width of zone (S2AZ)[d]
43	Distance, beginning of zone (CO) to C3
44 (60)	Distance, CO-C6
45	Distance, CO-C9
46 (62)	Distance, CO-C12
47	Distance, CO-C15
48 (64)	Distance, C3-C9
49	Distance, C3-C12
50 (66)	Distance, C3-C15
51	Distance, C6-C12
52 (68)	Distance, C6-C15
53	Distance, C9-C15

-Continued-

Appendix A. (page 2 of 2).

Variable	2nd Annular Zone
54 (70)	Distance, C(NC2AZ -6) to end of zone
55	Distance, C(NC2AZ -3) to end of zone
56	Distance, C3 to end of zone
57	Distance, C9 to end of zone
58	Distance, C15 to end of zone
59-71	Relative widths, (variables 43-55)/S2AZ
72	Average interval between circuli, S2AZ/NC2AZ
73	Number of circuli in first 1/2 of zone
74	Minimum distance between 2 consecutive circuli
75	Maximum distance between 2 consecutive circuli
76	Relative width, (variable 74)/S2AZ
77	Relative width, (variable 75)/S2AZ
78	Number incremental distances less than 10
79	Number incremental distances between 10 and 20
80	Number incremental distances greater than 20

Variable	Annular Zones Combined
81	Number circuli 1st + 2nd annular zones (NC1AZ+NC2AZ)
82	Width of 1st + 2nd annular zones, (S1AZ+S2AZ)
83	Average circulus width (variable 82/variable 81)
84	Relative width, S1AZ/(S1AZ+S2AZ)
85	Width 3rd annular zone (S3AZ)[e]
86	Total width 1st-3rd annular zones (S1AZ+S2AZ+S3AZ)

[a] Number of circuli, 1st annular zone.
[b] Size (width) 1st annular zone.
[c] Number of circuli, 2nd annular zone.
[d] Size (width) 2nd annular zone.
[e] Size (width) 3rd annular zone.

APPENDIX B: LINEAR REGRESSION OF FISH LENGTH

Appendix B. Linear relationship of tip-of-snout to fork-of-tail (TSFT) length measurements used to estimate mid-eye to fork-of-tail (MEF) measurements for spawning Yukon Territory fall chum salmon, 1985.

Sex	Sample Size	Relationship	Rgression Coefficient
Males	271	MEF = 36.98 + 0.831(TSFT)	$r2 = 0.922$
Females	527	MEF = 38.01 + 0.856(TSFT)	$r2 = 0.930$

APPENDIX C: SCALE GROWTH MEASUREMENTS

Appendix C. Group means, standard errors, and one-way analysis of variance F-test for the number of circuli and incremental distance of salmon scale annular growth zone measurements and MEF length measurements from age-0.3 male and female Yukon River chum salmon, 1987.

Stock Grouping	1st Annular Zone: Number of Circuli Mean	S.E.	F-Value	1st Annular Zone: Incremental Distance Mean	S.E.	F-Value	2nd Annular Zone: Incremental Distance Mean	S.E.	F-Value	MEF Length Mean	S.E.	F-Value
Males												
Toklat	27.60	0.20	2.076	542.40	4.85	5.279	329.31	5.02	1.597	575.77	3.86	35.044
Delta	28.09	0.25		552.56	5.96		343.65	5.98		600.65	3.32	
Bluff Cabin Sl.	27.96	0.22		548.33	5.72		336.81	4.43		592.61	2.87	
Chandalar	27.11	0.25		537.02	5.20		335.89	6.15		634.09	3.86	
Sheenjek	27.23	0.32		528.00	5.60		348.77	4.80		620.33	4.08	
Fishing Branch	27.33	0.20		529.96	4.42		334.96	4.41		598.88	2.82	
Mainstem Yukon	27.66	0.27		518.13	5.93		332.55	6.12		577.61	3.56	
Kluane	27.35	0.23		520.04	5.29		326.61	4.55		576.90	2.67	
Tanana	27.81	0.15	1.251	546.38	3.72	12.603	336.05	3.35	3.350	588.98	2.62	65.908
Porcupine	27.45	0.25		534.22	5.16		346.47	4.46		618.67	3.38	
Canadian Yukon	27.49	0.17		518.84	4.05		329.99	3.85		564.54	2.92	
Summer Chum Salmon	26.55	0.28	7.837	523.89	5.34	1.312	333.53	5.07	0.660	574.04	3.70	32.413
Fall Chum Salmon	27.54	0.21		532.11	4.52		338.65	3.80		603.35	3.29	
Females												
Toklat	27.77	0.19	3.040	536.64	4.46	5.520	323.75	5.22	1.917	556.64	3.42	18.908
Delta	28.18	0.24		548.68	4.59		340.44	5.42		588.33	3.90	
Bluff Cabin Sl.	28.53	0.27		561.45	6.72		340.49	6.14		565.82	3.76	
Chandalar	27.20	0.53		537.47	10.08		333.53	15.56		608.32	6.32	
Sheenjek	27.33	0.19		537.80	4.52		333.56	4.27		595.81	2.51	
Fishing Branch	27.98	0.30		539.83	6.55		333.94	6.07		586.58	3.74	
Mainstem Yukon	27.68	0.17		522.40	4.64		319.88	4.55		574.29	4.09	
Kluane	27.49	0.24		524.49	4.96		329.58	5.58		560.11	3.70	
Tanana	28.11	0.15	4.234	550.19	3.34	10.529	334.24	3.44	0.868	571.00	2.65	19.064
Porcupine	27.52	0.23		540.35	4.72		337.41	5.25		593.52	2.87	
Canadian Yukon	27.50	0.19		525.64	4.11		328.83	4.46		564.64	3.57	
Summer Chum Salmon	27.03	0.25	0.898	530.13	5.97	0.365	319.68	5.68	5.995	554.75	5.50	36.097
Fall Chum Salmon	27.36	0.20		534.75	4.18		339.23	4.39		587.58	2.64	